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NEW PROBLEMS OF COMETARY OBSERVATIONS FROM SPACE

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The possibility of treating the comets as natural probes of the solar system presents one of the attractive sides of cometary astronomy (Biermann and Lüst, 1966; Brandt and Hodge, 1964; Dobrovolsky, 1961). In connection with the plans to study comets from space, new aspects for comets as interplanetary probes are of interest. In the present report, possible meteor formation in cometary heads and the implication for space research are considered.

The travel of a comet through the interplanetary medium is accompanied--due to a large coma radius r_c ($> 10^8$ cm)--by a great number of collisions with interplanetary dust particles. The mean free path, L and the frequency of collisions, ν of a cometary coma with dust particles are:

$$L = \frac{1}{n(\pi r_c^2)} \sim 10^{-7} \text{ cm}, \qquad \nu = \frac{v}{L} \sim 10^{13} \ s^{-1} . \qquad (1)$$

The numerical estimate in (1) is given for heliocentric distances $R \approx 1$ a.u., where the probable concentration of dust particles is $n \sim 10^{-10}$ cm^{-3} and the mean relative velocity of cometary molecules and interplanetary grains meeting the comet, is $v \approx 6 \cdot 10^6$ cm/s.

The interplanetary particles colliding with the cometary coma will receive the thermal energy:

$$\left(\frac{dE}{dt} \right)_+ = \frac{\Lambda S \rho v^3}{2} , \qquad (2)$$

where Λ is the efficiency of energy transformation, and S is the area of the frontal section of a particle; ρ is the mass density of cometary gas along the particle path, which may be expressed as

$$\rho(r, R) \approx \frac{4 \pi Q(R) \mu m_H}{V_{T_m}} \left(\frac{r_o}{r} \right)^2 . \qquad (3)$$

Here Q(R) is the gas production rate of the cometary nucleus per cm^2·s·sr, μ is the mean molecular weight of the gaseous coma, m_H is the mass of the hydrogen atom, r_o is the radius of the cometary nucleus, r is the cometocentric distance, V_{T_m} is the mean thermal velocity corresponding to the gaseous coma temperature.

The energy radiated from the particle surface at temperature T, equals

$$\left(\frac{dE}{dt} \right)_- = 4 \epsilon \sigma S T^4 \qquad (4)$$

where ϵ is the integral coefficient of radiation, and σ is the Stephan-Boltzmann constant.

Equating the expressions (2) and (4) we find the quasi-stationary temperature of interplanetary particles crossing the coma:

$$T_s = \left(\frac{\Lambda \rho v^3}{8 \epsilon \sigma} \right)^{1/4} \qquad (5)$$

It should be noted that (4) and (5) are--on one hand--applicable to sufficiently large particles satisfying the condition of absence of diffraction effects: $a > \lambda_{\odot}/2\pi \approx 10^{-5}$ cm ($\lambda_{\odot}$ is the mean wavelength of the solar thermal radiation) and to sufficiently small particles satisfying the condition of the quasi-stationary heating:

$$\tau_{tr} > \tau_{\lambda}; \quad \tau_{tr} > \tau_{T} \tag{6}$$

on the other hand. Here $\tau_{tr} \approx r/v$ is the characteristic particle travel time for a certain zone of the coma: $\tau_{\lambda} = c\delta a^2/(4\lambda)$ is the characteristic time of particle heating due to heat conductivity (c, λ and δ denote, respectively, the specific heat capacity, heat conductivity and the density of particles). $\tau_T = 4\pi c\delta a^3/(3\varepsilon\sigma T_s{}^3)$ is the characteristic time for heating the particle up to quasistationary temperature $T = T_s$ (Ibadov, 1979). For the iron-silicate particles with the characteristic values of $\tau_{tr} \sim 1$ s, $c \sim 10^7$ erg/g·K, $\delta \sim 1$ g/cm^3, $\lambda \sim 10^6$ erg/(cm·s·K), $\varepsilon \approx 1$, $T \sim 10^3$K, according to (6) we have $a \lesssim 0.1$ cm. Thus, formula (5) is applicable to the overwhelming (by mass) part of the interplanetary particles hitting the head.

We assume that intense evaporation of the particles begins at $T \approx 2000$ K. Then the necessary condition for meteor appearance in the coma may be written, on the basis of (3) and (5), in the form

$$\left(\frac{\pi \Lambda \mu m_H \, Q \, v^3}{2\varepsilon\sigma v_{T_m}}\right)^{1/4} \left(\frac{r_o}{r_u}\right)^{1/2} \approx 2000 \text{ K}. \tag{7}$$

where r_u is the upper boundary of meteor appearance.

Taking in (7) $r_u \approx r_o$ we may find the minimal gas production rate of the nucleus Q_{min} allowing meteor generation as

$$Q_{min} \approx \frac{32 \cdot 10^{12} \, \varepsilon\sigma v_{T_m}}{\pi \Lambda \mu \, m_H v^3} \tag{8}$$

It can be shown that the velocity of coma meeting particles, averaged over the frontal hemisphere can be approximated by the expression

$$v \equiv v(R) \approx 6 \cdot 10^6 \, R^{-1/2} \text{ cm/s} \tag{9}$$

with R in a.u. Introduction of (9) in (8) gives

$$Q_{min} \approx \frac{16 \cdot 10^{-6} \, \varepsilon\sigma v_{T_m} \, R^{3/2}}{27 \, \pi \Lambda \, \mu \, m_H} \tag{10}$$

According to (10) we get $Q_{min} \approx 2.5 \cdot 10^{15}$ molec/(cm^2·s·sr) at typical values $R \approx 1$ a.u., $v_{T_m} \approx 5 \cdot 10^4$ cm/s, $\varepsilon \approx 1$, $\Lambda \approx 1$, $\mu \approx 30$. For bright comets $Q \equiv Q(R) \sim 10^{18}/R^2$ molec/(cm^2·s·sr), so the meteor phenomena will develop at $R \lessapprox 1$ a.u. in the heads of many comets and, in particular, in the head of Halley's comet near its perihelion ($q \approx 0.5$ a.u.).

It is more convenient to express the "upper" boundary of meteor appearance, r_u, through the total gas production rate of the cometary nucleus Q [molec/s] thus excluding the unknown r_0. Indeed, assuming the homogeneous emission Q [molec/s] $= 4\pi r_0^2$ Q[molec/(cm^2·s·sr)] and using relations (7) and (9) we obtain

$$Q\ [\text{molec/s}] \approx \frac{16 \cdot 10^{-6}\ \varepsilon \sigma v_{T_m}\ R^{3/2}}{27 \pi \Lambda \mu\ m_H}\ r_u^2. \qquad (11)$$

Adopting earlier mentioned values of parameters entering the right-hand side of (11), we obtain $r_u \approx 10^7$ cm for $Q = 10^{30}$ molec/s at $R \approx 1$ a.u. and $r_u \approx 10^8$ cm for $Q \sim 10^{31}$ molec/s at $R \sim 0.1$ a.u.

On the other hand, equation (11) gives a new method for determining Q provided r_u is known. r_u can be determined, for instance, by measurement of the temperature of an artificial probe in a form of a droplet or, better in form of a bubble with very thin walls.

The registration of the products of meteor processes in the heads of comets could give information about the spatial density of solid particles $\rho_s(R)$ in the interplanetary medium. Estimates show that interplanetary particles with masses $\lesssim 10^{-8}$ g, moving in the opposite direction to the cometary motion, fully disintegrate in the Halley type comas at $R \lesssim 1$ a.u. This results in formation of a cloud of atoms of refractory elements in the head. For instance within the angular limits given approximately by r_u/Δ (Δ is the comet-observer distance), the column density of iron atoms in a Halley type comet, N(Fe) ~ 10^9 atom/cm^2, is achieved at $R \sim 0.5$ a.u. provided $\rho_s(0.5) \sim 10^{-22}$ g/cm^3. This value exceeds by many orders of magnitude the atom concentration due to evaporation of cometary dust particles in the thermal radiation field of the Sun (Ibadov, 1980). So, the problem of registration of cometary emission in atomic lines of refractory elements (Fe, Ni, Si, etc.) at large heliocentric distances becomes topical.

These emissions could be detected by a detailed study of the Fraunhofer profiles of cometary spectral lines when the heliocentric radial velocities are non-zero.

Of course, the probable appearance of meteor phenomena in the heads of comets indicates the potential possibility of their study also on the basis of meteor astronomy methods. The further development of all these methods in the program of cometary observations from space would expand the informativity of cometary investigations.

References

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